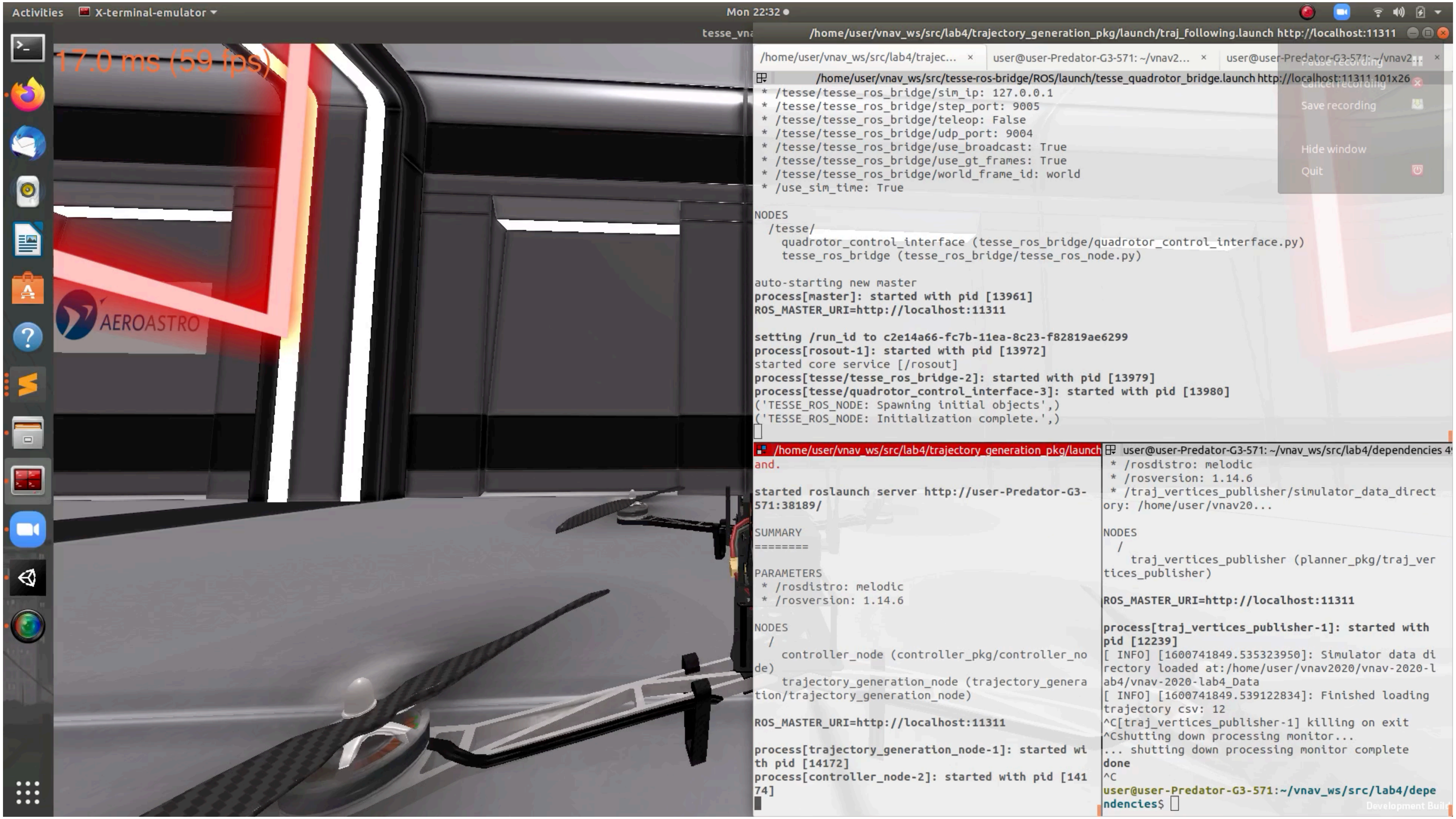
16.485: VNAV - Visual Navigation for Autonomous Vehicles

Lecture 11: Image Formation

Luca Carlone

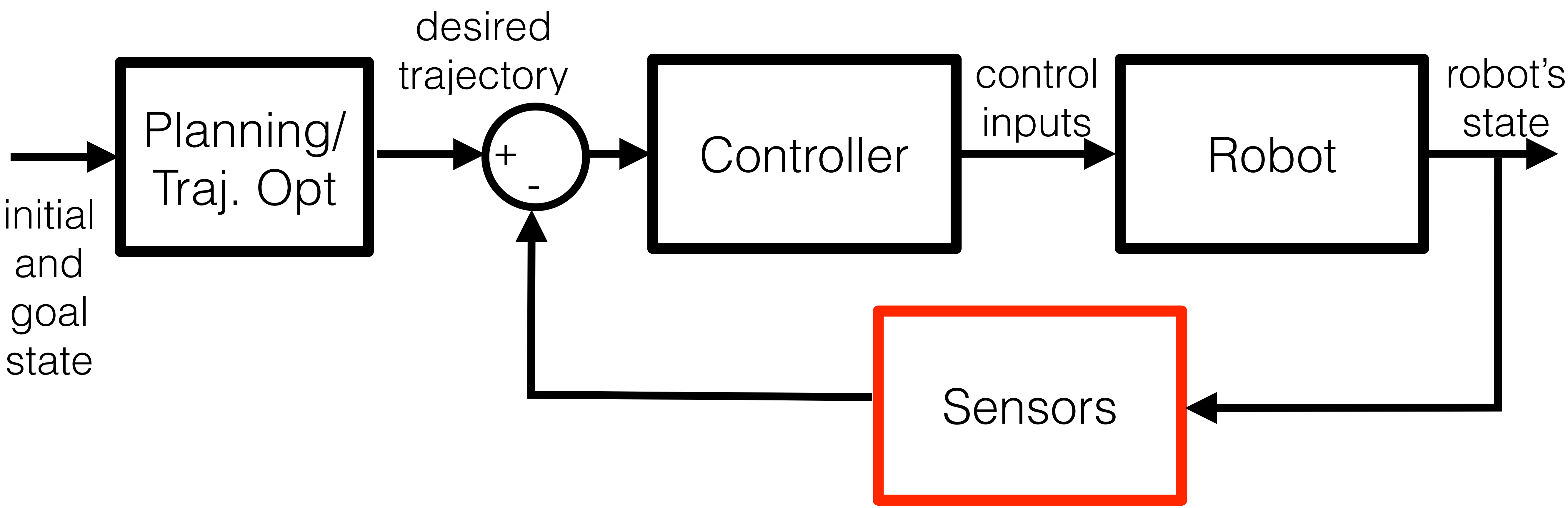
What we learned so far



Requires:

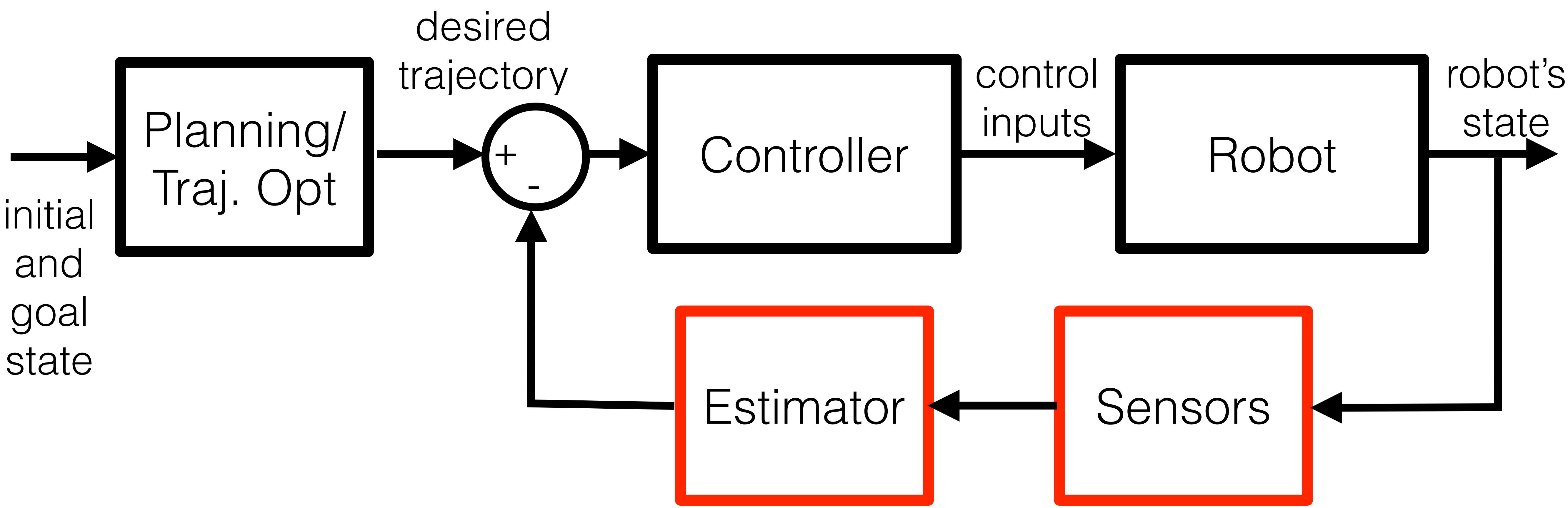
- state of the drone (localization)
- obstacles (mapping)

What's next



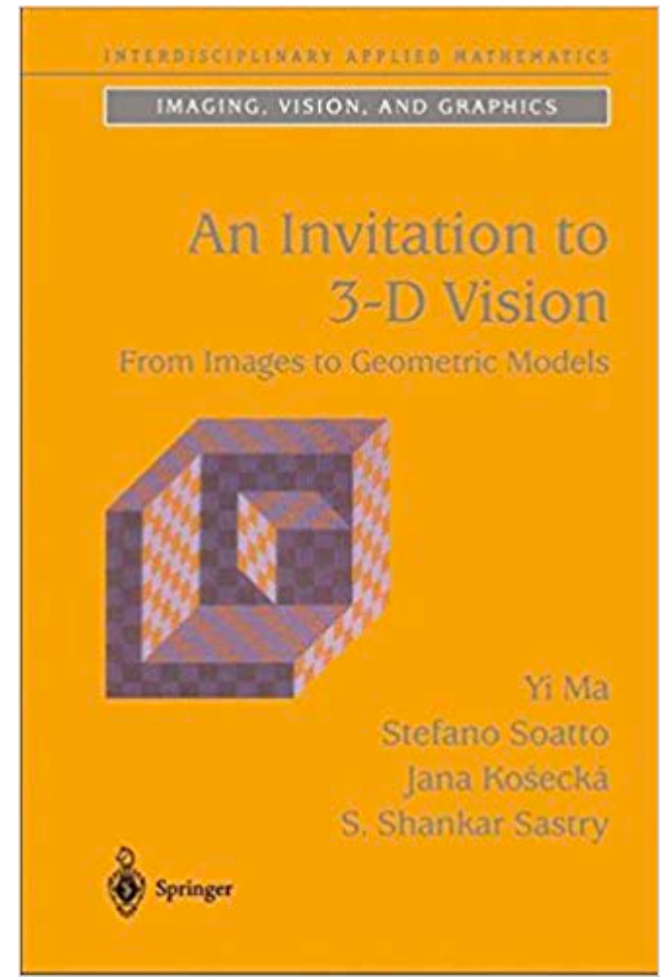
desired
trajectory
control
inputs
robot's
state
Planning/
Traj. Opt
+
-
Controller
Robot
initial
and
goal
state
Sensors

What's next


desired
trajectory
Planning/
Traj. Opt
+
-
Controller
control
inputs
Robot
robot's
state
initial
and
goal
state
Estimator
Sensors

Today

- Image Formation
- Pinhole Camera Model

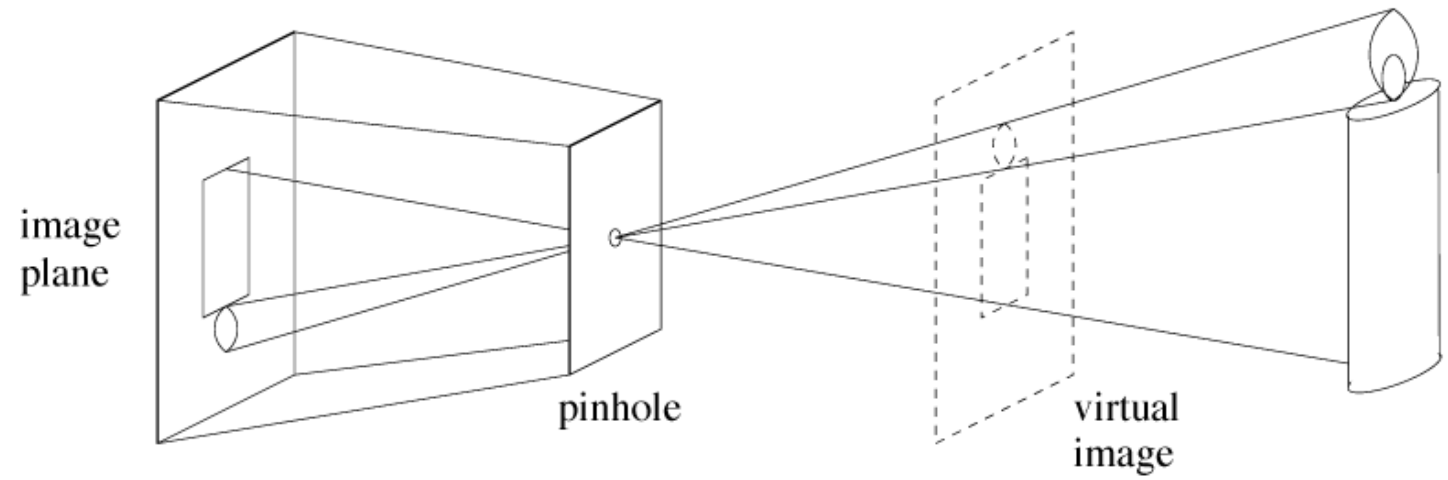


Chapter 3

Image Formation

Image Formation

- How to capture a 3D scene on a 2D image?

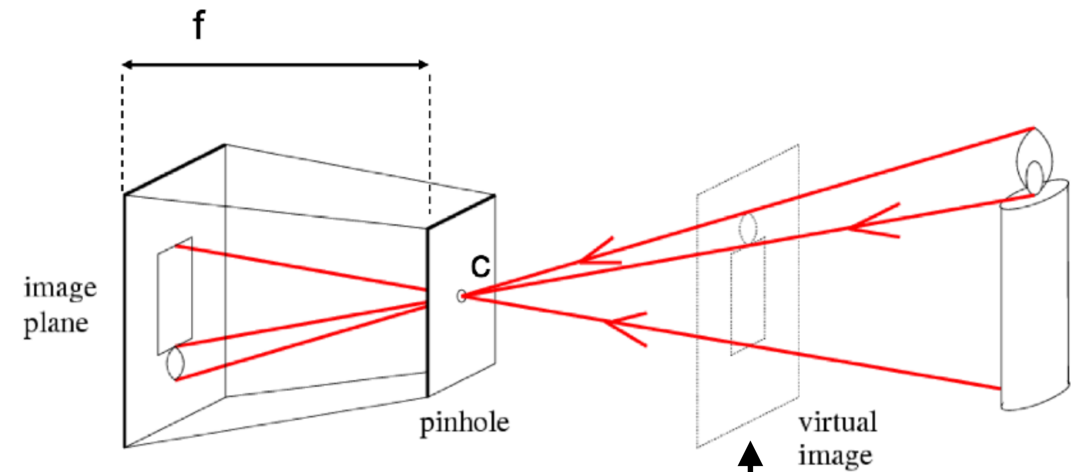


- **Camera obscura** (Latin: “dark room”):
    - optical device that projects 3D scene to a surface
    - box with a hole on one side
    - known for several centuries:
        - Mo Ti, Chinese philosopher (5^{th} Century B.C.)
        - Leonardo da Vinci (1452-1519)

Frisius (1544)

Geometry: Pinhole Camera Model

- How to compute the 2D projection (pixel) of a given 3D point?



f = focal length
c = center of the camera

Frontal pinhole model

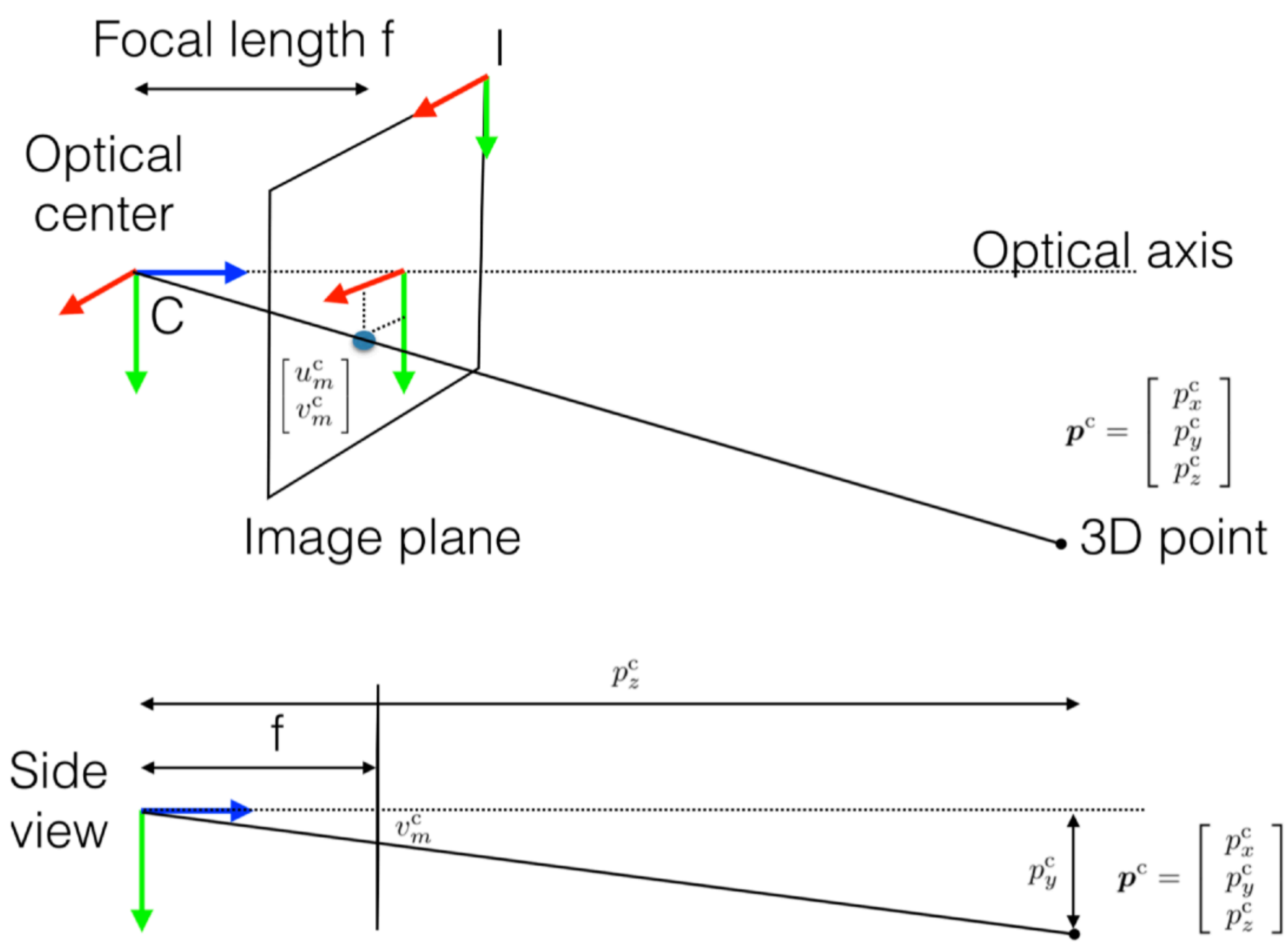
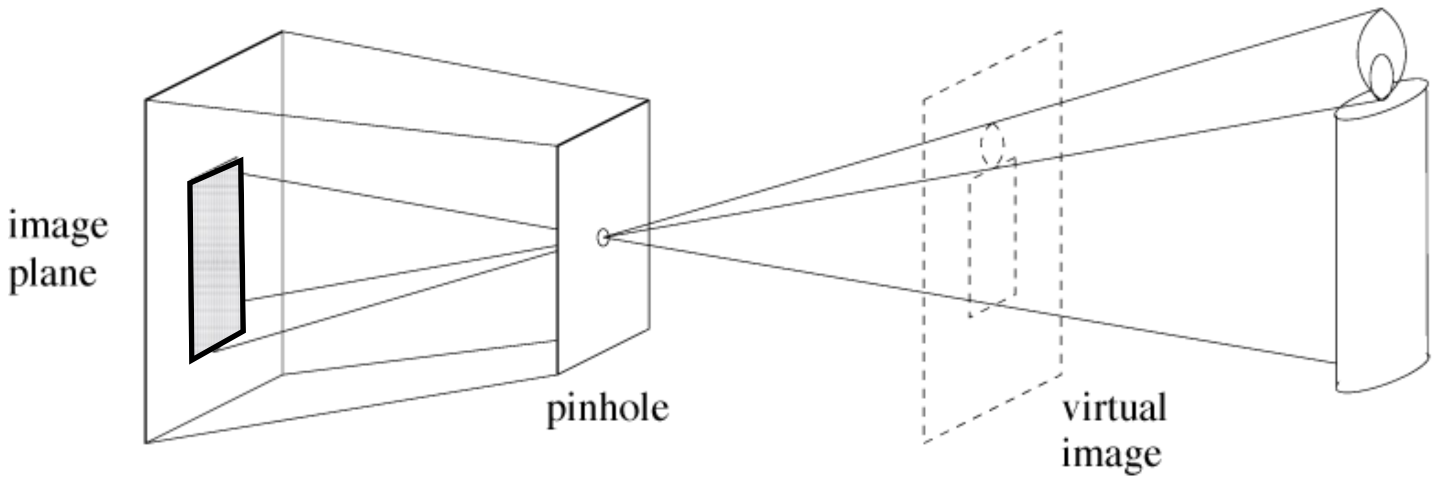


Figure 11.1: Pinhole Model.

Let's do some math

Digital Photography



2D array of
"light sensors"

- CCD (charge-coupled device, 1960)
- CMOS (complementary metal-oxide semiconductor, 1963)

0.92	0.93	0.94	0.97	0.62	0.37	0.85	0.97	0.93	0.92	0.99
0.95	0.89	0.82	0.89	0.56	0.31	0.75	0.92	0.81	0.95	0.91
0.89	0.72	0.51	0.55	0.51	0.42	0.57	0.41	0.49	0.91	0.92
0.96	0.95	0.88	0.94	0.56	0.46	0.91	0.87	0.90	0.97	0.95
0.71	0.81	0.81	0.87	0.57	0.37	0.80	0.88	0.89	0.79	0.85
0.49	0.62	0.60	0.58	0.50	0.60	0.58	0.50	0.61	0.45	0.33
0.86	0.84	0.74	0.58	0.51	0.39	0.73	0.92	0.91	0.49	0.74
0.96	0.67	0.54	0.85	0.48	0.37	0.88	0.90	0.94	0.82	0.93
0.69	0.49	0.56	0.66	0.43	0.42	0.77	0.73	0.71	0.90	0.99
0.79	0.73	0.90	0.67	0.33	0.61	0.69	0.79	0.73	0.93	0.97
0.91	0.94	0.89	0.49	0.41	0.78	0.78	0.77	0.89	0.99	0.93

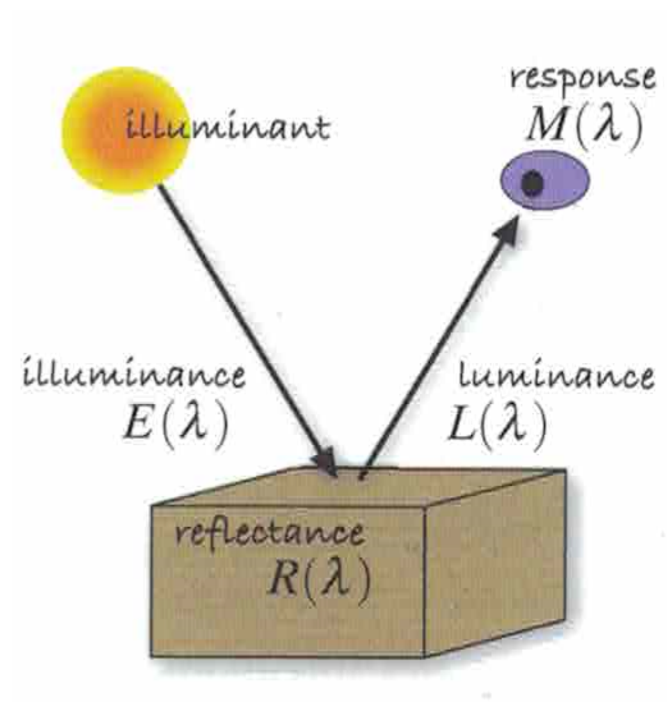
Appearance: Light and Colors

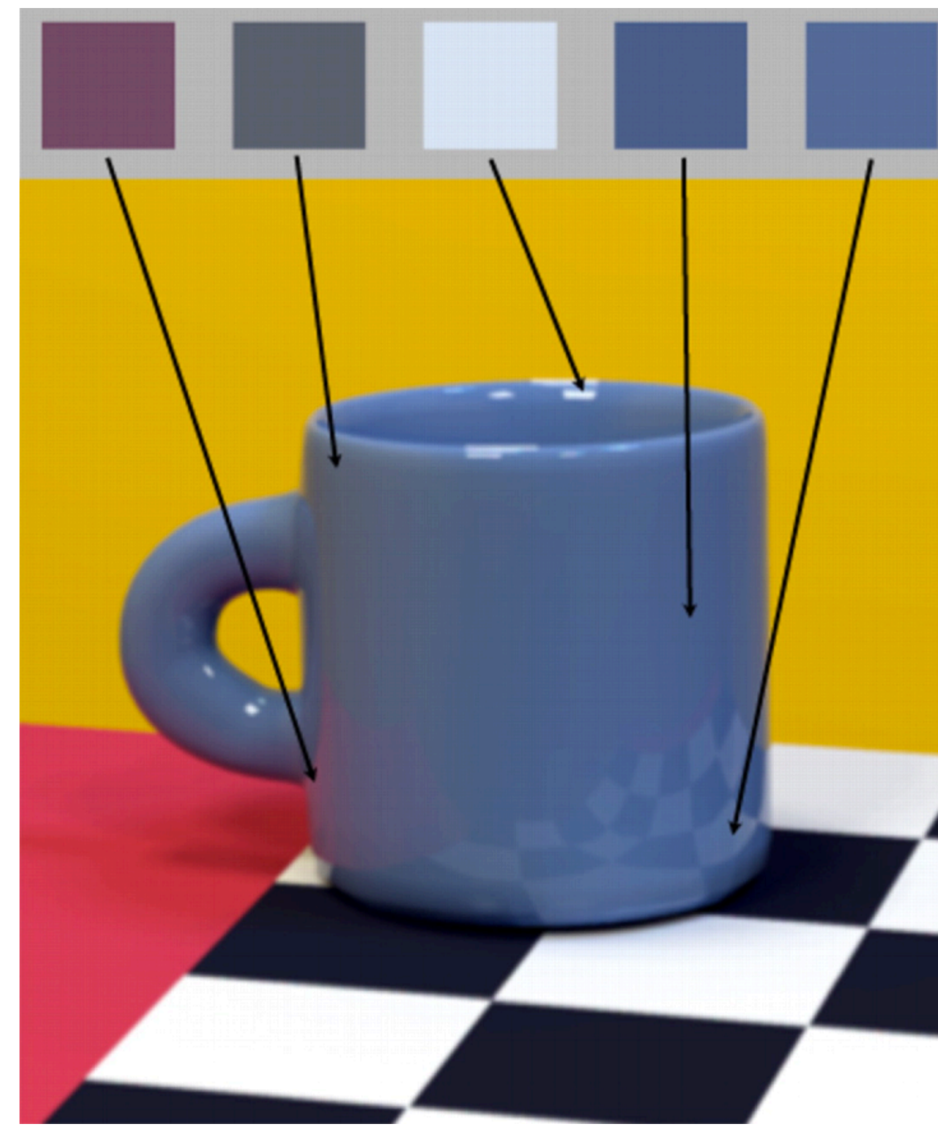
R
(G=0,B=0)

G
(R=0,B=0)

B
(R=0,G=0)

Perceived appearance is the result of (i) geometry, (ii) illumination, (iii) material properties

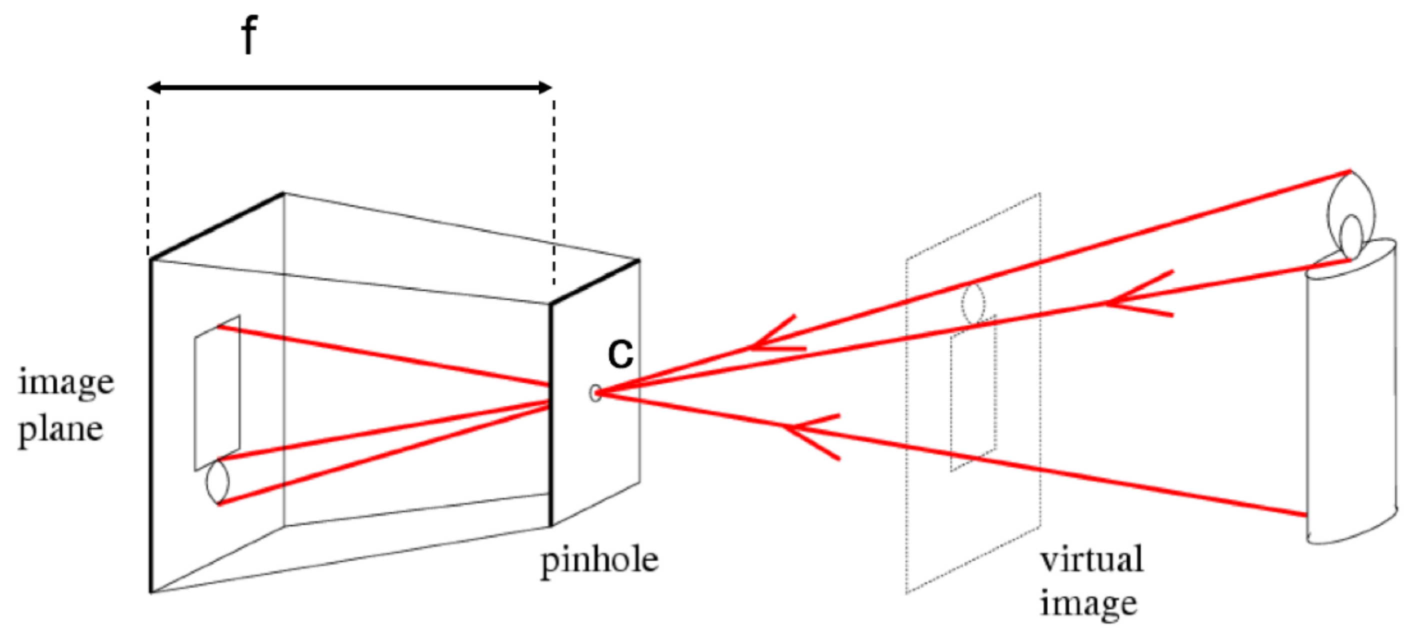




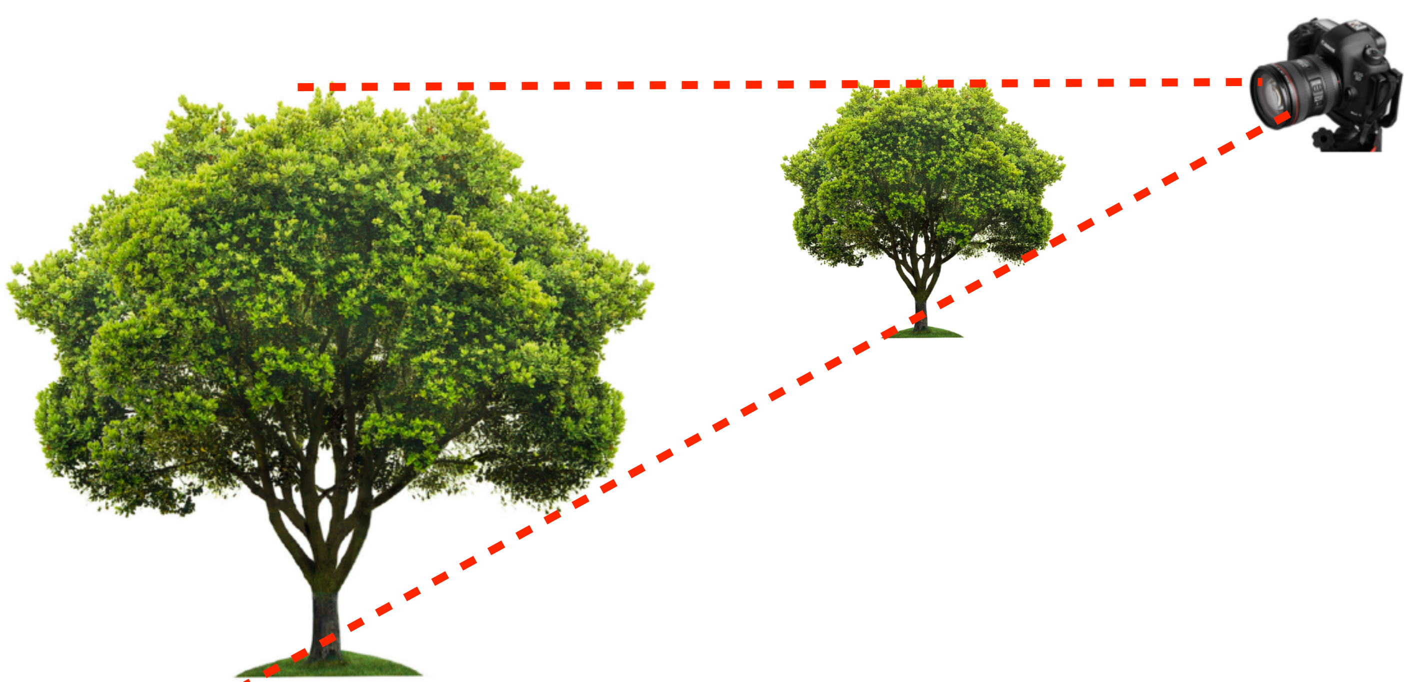
MIT AEROASTRO

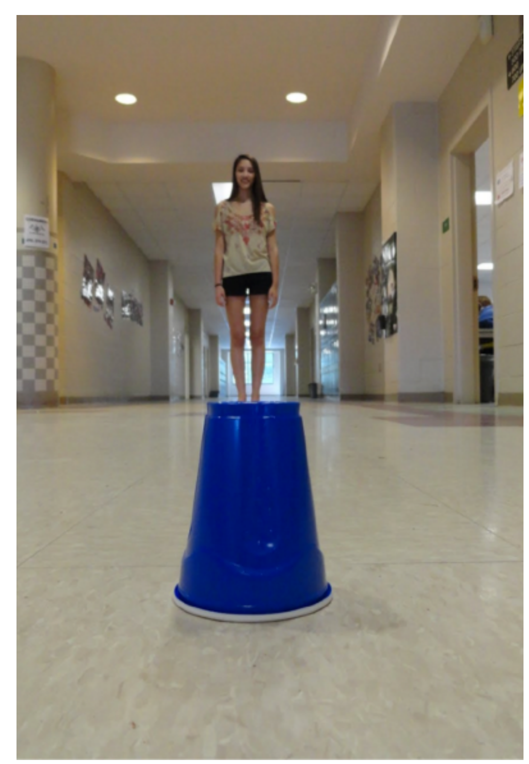
Perspective Projection

- what is lost?
  - depth?

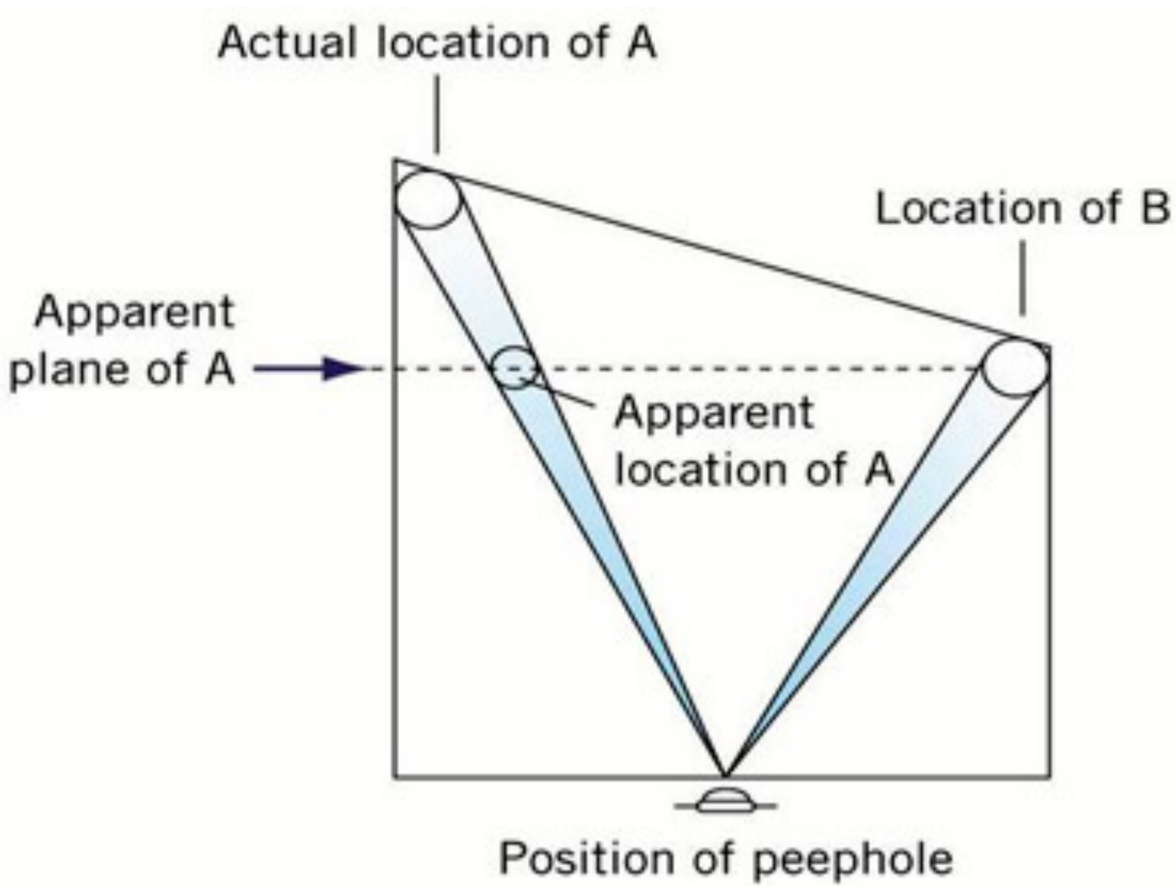


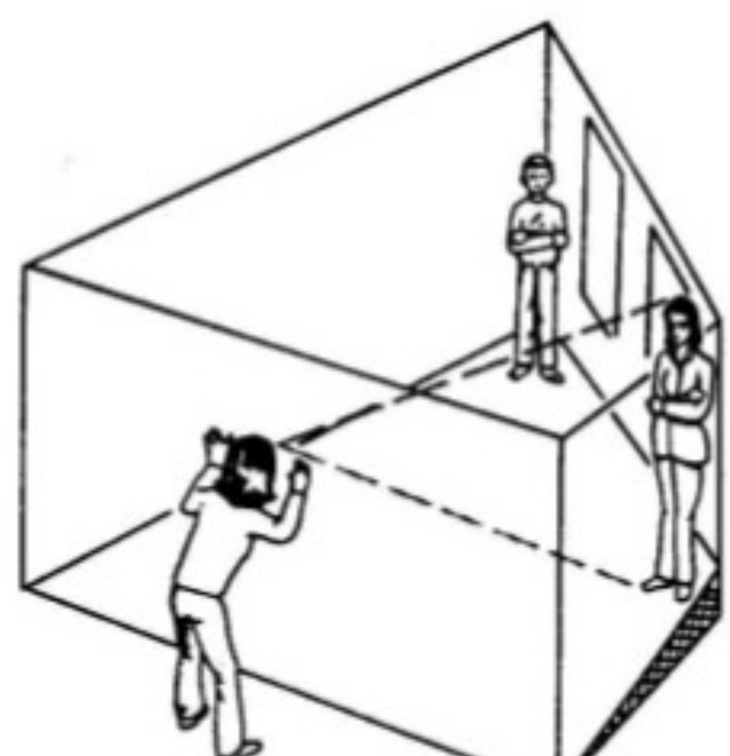
f = focal length
c = center of the camera





Ames Room

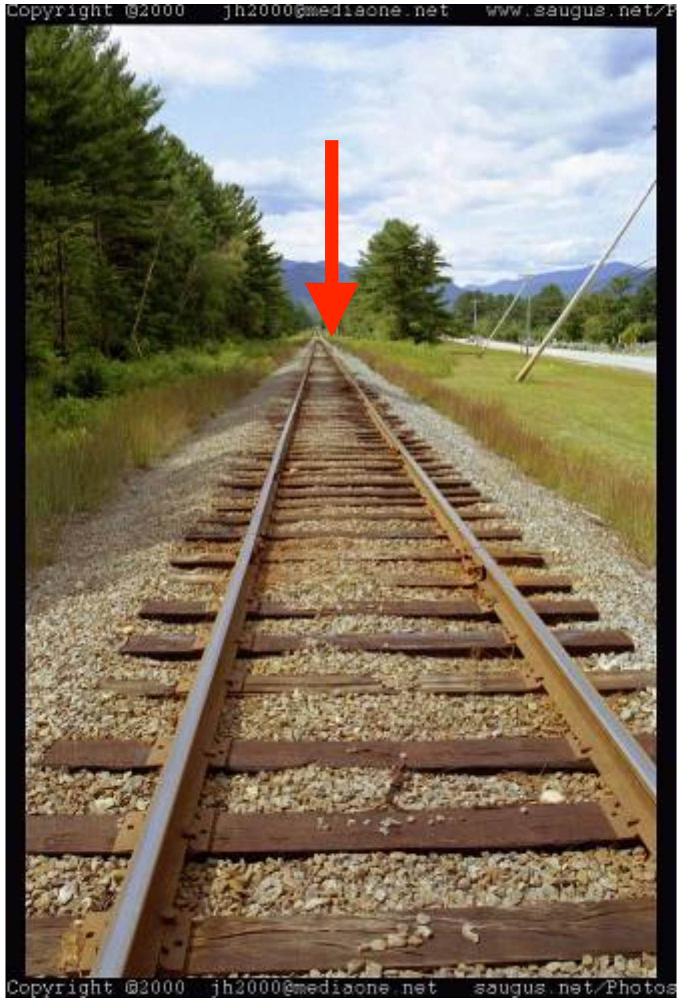


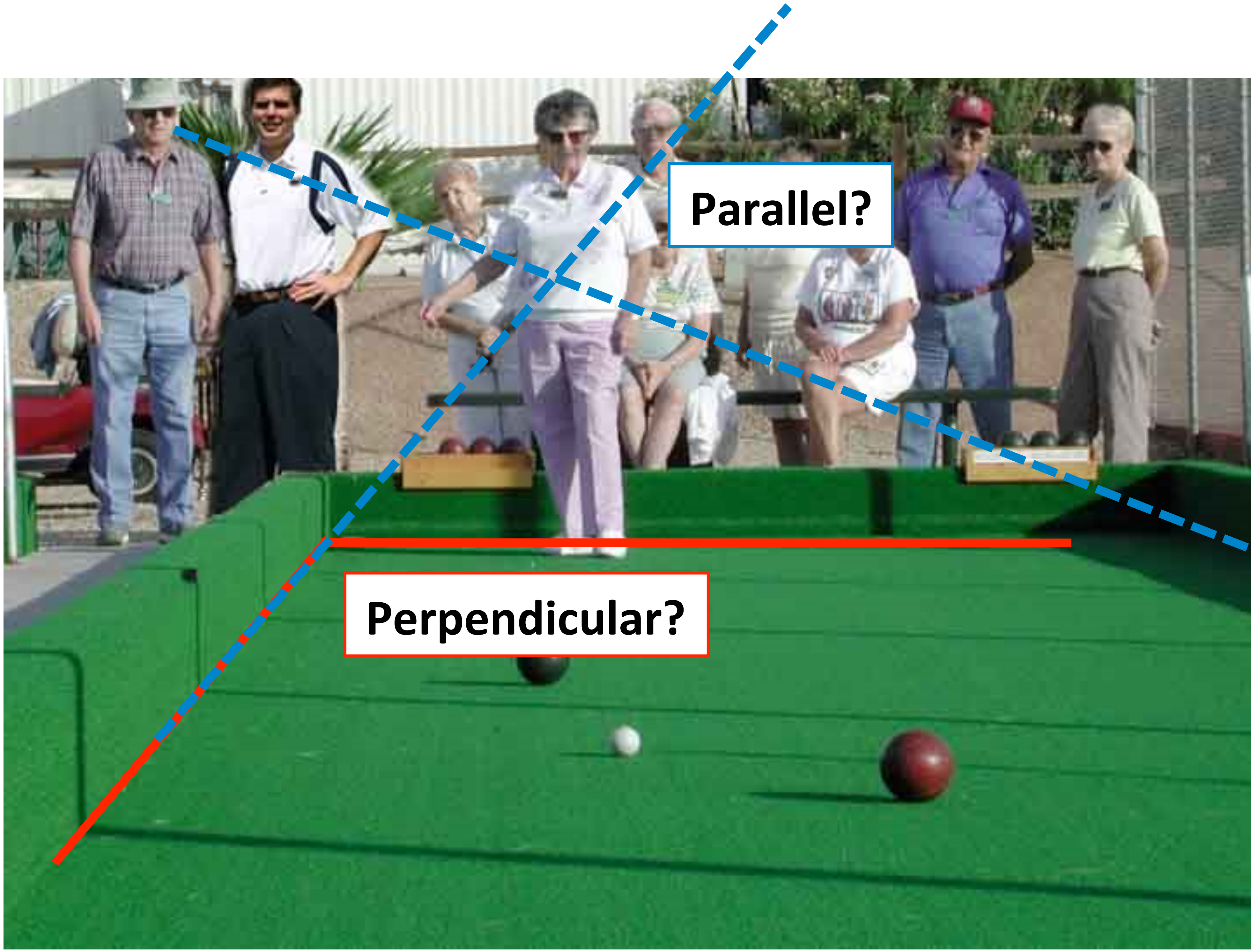


Ames, 1946

Perspective Projection

- what is lost?
  - depth?
  - length?
  - angles?



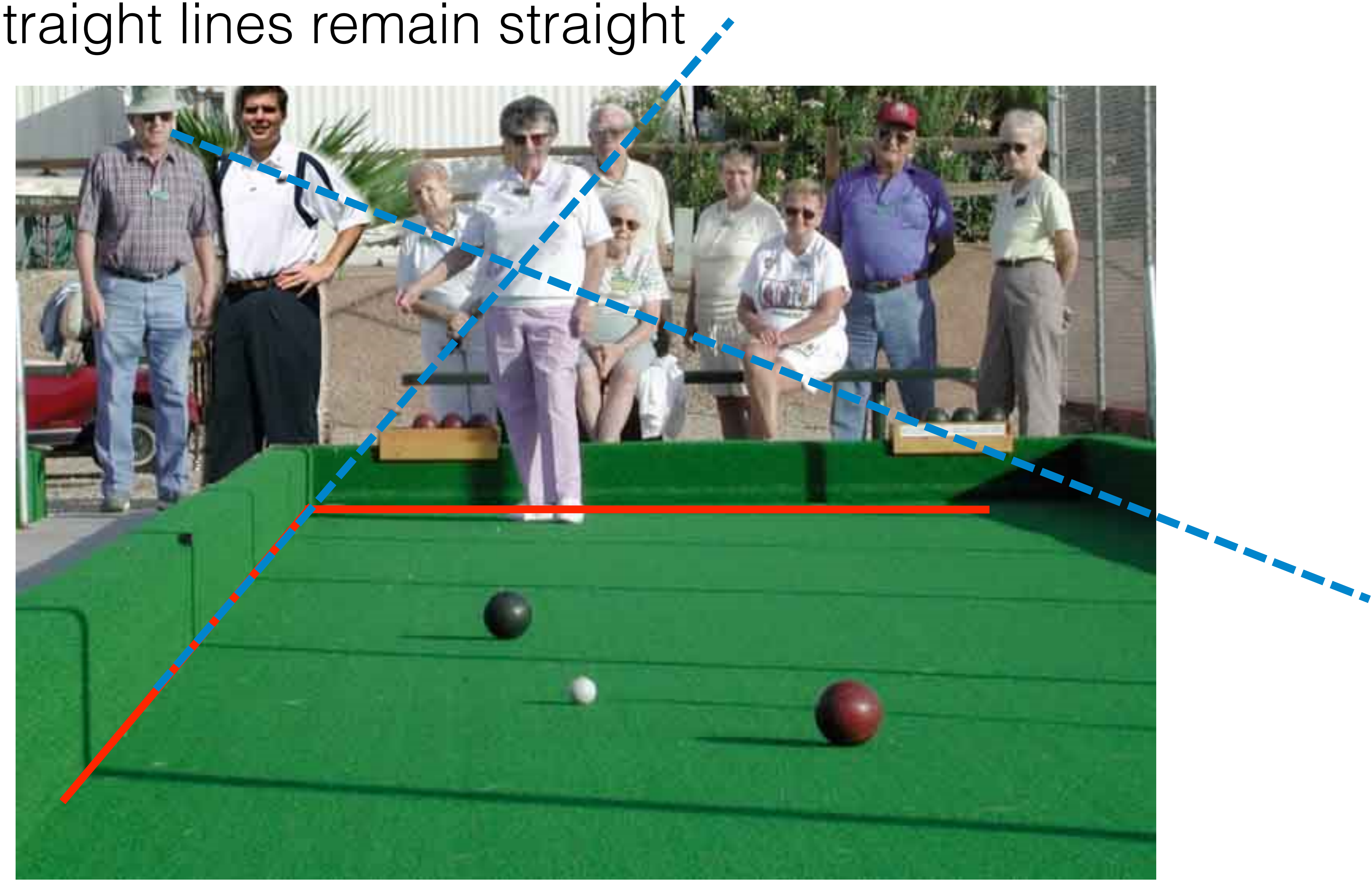


Parallel lines which intersect …

Slide adapted from Frank Dellaert

Perspective Projection

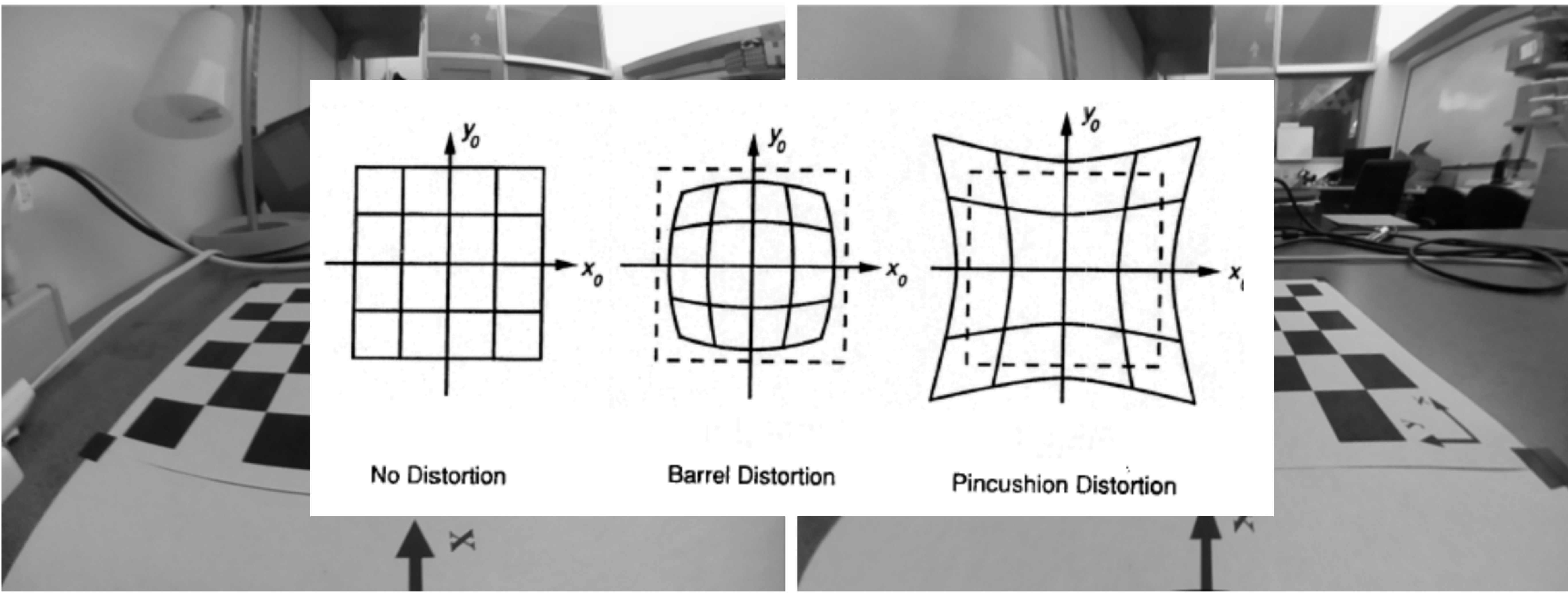
- what is preserved?
  - straight lines remain straight



Slide adapted from Frank Dellaert

The final Touch: Adding a Lens

- Pinhole model is based on the geometry of the **camera obscura**
- In practice: add a **lens** in front of the aperture to capture more light
- Pinhole model holds, but **distortion** may appear due lens imperfections



- distortion can be described mathematically using **distortion parameters**
  - can be estimated during calibration and compensated for (**undistortion**)